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Effect of γ irradiation on the physico-mechanical and chemical properties of potato (*Solanum tuberosum* L), cv. 'Kufri Chandramukhi' and 'Kufri Jyoti', during storage at 12 °C

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HIGHLIGHTS

- Sprouting completely inhibited at 0.05 kGy during storage at 12 °C.
- Irradiated (0.05–0.5 kGy) tubers looked firm and retained high textural parameters.
- Micrographs showed no damage to the cell walls at doses upto 0.5 kGy.
- No loss of tubers due to rotting was observed at 0.05 and 0.15 kGy.
- Dose-dependent accumulation of reducing and total sugars.

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ABSTRACT

The study was carried out on two important cultivars of potato, 'Kufri Jyoti' and 'Kufri Chandramukhi', to evaluate the effectiveness of low dose gamma irradiation (0.05, 0.15 and 0.5 kGy) in maintaining the tuber qualities in terms of textural parameters (puncture force, shear force, work done, cohesiveness and gumminess), microstructure, sugar content and storage losses during storage of 120 days at 12 °C. Sprouting was completely inhibited even at the lowest dose studied, i.e., 0.05 kGy. All the irradiated tubers looked firm with no deterioration in appearance. The irradiated tubers retained higher textural parameters compared to the unirradiated controls. It was interesting to observe a noticeable increase in the textural parameters of the irradiated specimens of 'K. Chandramukhi'. The scanning electron micrographs showed all the irradiated specimens with rigid cell walls. A dose dependent accumulation of reducing and total sugars was observed. Minimum accumulation of sugars occurred at 0.05 kGy. No loss of tubers due to rotting was observed at 0.05 and 0.15 kGy as compared to 6% loss observed in unirradiated controls. Thus, low dose irradiation (up to 0.15 kGy) with storage at 12 °C is an effective postharvest method for preserving the tuber qualities in potato.

1. Introduction

India is the largest potato producer of South West Asia but potato storage is a major problem for the country (Ezeta, 2008). Cold storage at 2–4 °C is the most commonly used method that successfully provides solutions to many problems such as sprouting, rotting, tuber moth damage and weight loss but accumulation of reducing sugars makes the tubers unsuitable for processing purpose (Van Es and Hartmans, 2008). The distribution of cold storages is uneven in the country (Johl and Dahiya, 2002). Cold storage is high energy consuming that also makes it costly. Storage at 10–12 °C is less energy consuming and prevents undesirable accumulation of reducing sugars so potatoes for the processing purpose are stored at this temperature but requires application of sprout suppressants. The use of chemical sprout suppressants has also raised concern regarding their harmful residual effects (Kleinkopf et al., 2003). Gamma irradiation is a safe and effective method of sprout inhibition that allows potatoes to be stored at high temperatures (Siddiqui et al., 1973; Thomas, 1984; Hossain et al., 1995; Frazier et al., 2006). The number of γ irradiation facilities is also growing in the country as the technique is steadily gaining worldwide acceptance (EIR, 2008).

The radiation induced sprout inhibition is probably as a result of DNA damage, affecting the biosynthesis of certain plant growth

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hormones and enzymes, thus interfering with the normal metabolism of the tuber (Diehl, 1995). The interaction of high energy radiations with the structural and chemical components of potato can also affect the tuber qualities. A number of studies have been reported on the effect of gamma irradiation on different tuber qualities such as sugar content, vit C content, chipping quality etc. (Frazier et al., 2006; Ezekiel et al., 2008a, 2008b; Rezaee et al., 2011, 2013). Texture is an important quality parameter that determines the acceptability and shelf-life of a fresh horticulture produce. It is primarily determined by the structural integrity of the cell wall and middle lamella as well as turgor pressure of the cells (Jackman and Stanely, 1995; Van Buggenhout et al., 2009). Insoluble starch granules stored in the tubers also play important role in potato texture (Singh et al., 2005). The mechanical properties of stored potatoes is influenced by the physiological changes involving structural components of the tissues in relation to loss of cell water by evaporation and production of cell water by respiration (Gao et al., 1989; Alvarez and Canet, 2000). The increased physiological losses at higher storage temperature reduce their storability that ranges between 3 and 4 months at 10 °C (Eltawil et al., 2006). A good postharvest technology should minimize storage losses and physico-chemical changes during storage. So, the present study was carried out to evaluate its effectiveness of gamma irradiation in maintaining tuber qualities in terms of textural parameters, microstructure, sugar content and storage losses during storage at 12 °C.

2. Materials and methods

2.1. Potato harvest and packaging

'K. Chandramukhi' and 'K. Jyoti' were procured from the farms of Bidhan Chandra Krishi Viswavidyalaya. The tubers were harvested during the months of February and March respectively, and kept in an airy room (22–27 °C) for about a week for curing. The properly cured, well suberised samples were transported to the laboratory packed in nylon bags and were stored on the floor of a cool, airy, dry room (20–22 °C). The potatoes were irradiated after 30 days of harvest.

For irradiation, equal sized potatoes (55–60 g) of each cultivar were packed separately in aerated low density polyethylene (LDPE) bags (thickness: 44 μm) measuring 21.5 cm × 15 cm. Holes were cut in the bags to facilitate gaseous exchange. Six bags each containing eight to ten potatoes were included at each dose. Six such bags were kept unirradiated as control (0 kGy).

2.2. Gamma-irradiation

Gamma irradiation was carried out at the Food Irradiation Laboratory, NIL Campus, Jadavpur University, Kolkata using Co-60 gamma cell (Model: Gamma Chamber 5000, BRIT, Mumbai) with source strength of 499.5 TBq. The dose rate during the study was 2.6 Gy/s. The potatoes were irradiated with varying low doses of γ-ray (0.05 kGy, 0.15 kGy and 0.5 kGy).

2.3. Storage

The unirradiated and the irradiated samples of potatoes were stored in a humidity cabinet (Prime Instruments) for 120 days at 12 ± 1 °C (RH: 85–90%). The physico-chemical and textural observations were performed on 0 day, 60 days and 120 days of storage.

2.4. Sprout percentage

Tuber having at least one sprout of 0.5 cm length or more was recorded as sprouted (Mehta and Kaul, 2002), and the percentage of sprouting was calculated for each dose.

2.5. Rotting percentage

Any tuber showing a sign of soft rot or mould was considered as decayed. The percentage of rotting was calculated for each dose.

2.6. Total and reducing sugars

The reducing and total sugar content of the unirradiated and irradiated samples were determined during storage by the di-nitro salicylic acid (DNSA) method (Plummer, 2008). Calibration plot was drawn using a standard glucose solution in the range of 0–1.0 g/L. 10 g of peeled potato was cut and ground with a pestle and mortar. The homogenized paste was suspended in 20 mL of distilled water, filtered through a muslin cloth and centrifuged at 2516 × g for 15 min. The supernatant was used to determine the reducing sugars. For the estimation of total sugar, 200 μL of the supernatant was added to 800 μL of distilled water in a test tube and hydrolyzed with 172 μL of 12 N HCl at 68 °C for 8 min. The hydrolyzed sample after neutralization with 20% NaOH, was used for the determination of total sugars. OD was measured spectrophotometrically (Spectrophotometer U-1800, Hitachi) at 540 nm. The reducing sugar (mg/kg) on a fresh weight basis and total sugar content (mg/kg) on a fresh weight basis was calculated from the standard plot of glucose.

2.7. Textural analyses

Texture analyses of the unirradiated and irradiated potato tubers were done by puncture test, shear test and double compression test using Instron Universal Testing Machine (Model 4301, Instron Ltd. UK).

2.7.1. Puncture test

The whole potato tuber was placed on the base plate and punctured along its width from one end to another by a cylindrical puncture probe of 6 mm diameter driven through the potato from one end to another at a crosshead speed of 0.25 mm/s under the working load of 100% of 100 N load cell. The highest peak required to puncture through the flesh of the tuber was recorded in Newton (N), indicating tuber firmness. The work done (or toughness) to puncture the tuber was calculated as the area under the force–distance graph obtained, expressed in Newton metre (N m) (Rosenthal, 1999).

2.7.2. Shear test

The whole potato tuber was placed on the base plate and cut through its cross section by "V" shaped Warner–Bratzler Meat Shear Compressive type blade driven at the speed of 0.25 mm/s under the working load of 20% of 1000 N load cell. The force–distance graphs obtained were compared by the peak force (N) required to shear through the flesh of the tuber. The work done (or toughness) to shear the potato was calculated as the area under the graph obtained, expressed in N m.

2.7.3. Double compression test

Double compression test was performed using 50% working load of 1000 N load cell on cylindrical samples (2.5 cm dia × 1 cm) that were compressed (25% compression) on a non lubricated platform using flat disc probe of 40 mm diameter moving at a speed of 0.25 mm/s. The cohesiveness and gumminess were determined from the Texture Profile Analysis (TPA) graphs (Bourne, 1978). Cohesiveness is expressed as the dimensionless quotient of the areas represented by the work to be done for two bites. Gumminess

is defined as the product of hardness and cohesiveness

$$\text{Cohesiveness}: \frac{\text{Area of the graph obtained during second compression (N m)}}{\text{Area of the graph obtained during first compression (N m)}}$$

$$\text{Gumminess (N)}: \text{Hardness (N)} \times \text{Cohesiveness}$$

2.8. Scanning electron microscopy

Scanning electron microscopy of the potato samples was carried out after 60 days of storage. Small, thin sections of potato tissue were cut from the whole potato using sharp blade and dehydrated using Freeze Dryer (Eyela, FDU 1200). Samples thus prepared, were viewed in Scanning Electron Microscope (SEM) with magnification of 200 ×.

2.9. Statistical analysis

The physico-chemical determinations of unirradiated and irradiated potato tubers were made in 3 replications and presented as mean value ± standard deviation (SD). The data were subjected to Duncan's Multiple Range Test (DMRT) (Gacula and Singh, 1984) and statistical significance was tested at $p \leq 0.05$.

3. Results and discussion

3.1. Textural analyses

Tuber firmness and toughness were studied by puncture test and shear test. No significant effect of increasing irradiation doses (up to 0.5 kGy) was observed on the puncture force. All the irradiated tubers maintained high puncture force during storage of 120 days at 12 °C, while the unirradiated controls registered peak force significantly lower. It was interesting to observe that 'K. Chandramukhi' exposed to 0.05, 0.15 and 0.5 kGy showed an increase of puncture force by 41%, 32% and 32% respectively, after 120 days at 12 °C. The 'work done' to puncture the tubers (i.e., toughness) also increased by 46%, 32% and 32% at the respective doses (Fig. 1). Similar to puncture test, the shear test also revealed similar trends. The irradiated tubers of 'K. Chandramukhi' showed an increase of shear force by 12–16%, while toughness increased by 6–16% (Fig. 2). The irradiated tubers of 'K. Jyoti' did not show such marked increase but maintained their textural parameters during storage.

Consistent with the puncture and shear test, the irradiated tubers of 'K. Chandramukhi' and 'K. Jyoti' retained their cohesiveness and gumminess during 120 days storage. Cohesiveness is defined as the work required to overcome the internal bonding of the material and gumminess is the energy required to disintegrate semisolid food to a state ready for swallowing (Bourne, 1982). No significant difference in cohesiveness of the unirradiated and irradiated tubers was observed during the storage period, suggesting no cell wall damage caused by irradiation with doses up to 0.5 kGy or during storage at 12 °C. All the irradiated tubers retained their gumminess and were significantly higher than the controls (Fig. 3).

The textural deterioration in the control tubers might be due to sprouting that increases physiological losses from the tuber by increasing the rate of respiration as well as increased breakdown of stored starch into soluble sugars (Burton, 1989; Eltawil et al., 2006). Irradiation successfully inhibited sprouting and is known to restrict metabolism in potato, observed as reduced breakdown of starch as well as loss of tuber weight (Mahboob et al., 2004; Rezaee et al., 2011, 2013). It was unexpected to observe enhancement of textural parameters during storage at 12 °C but controlled physiological losses of the irradiated tubers at 12 °C (RH: 85–90%) preserved the textural characteristics of the tubers. Compared to 'K Jyoti', the irradiated tubers of 'K. Chandramukhi' showed a pronounced enhancement in their textural parameters during storage. This difference in their textural behavior might be related to the compositional and structural differences between the cultivars.

3.2. Microstructures

The scanning electron micrographs of the potato samples visualized the hexagonal cells cut open, revealing the starch granules (Fig. 4). No significant effect of irradiation with doses up to 0.5 kGy was observed on the microstructure and the irradiated specimens

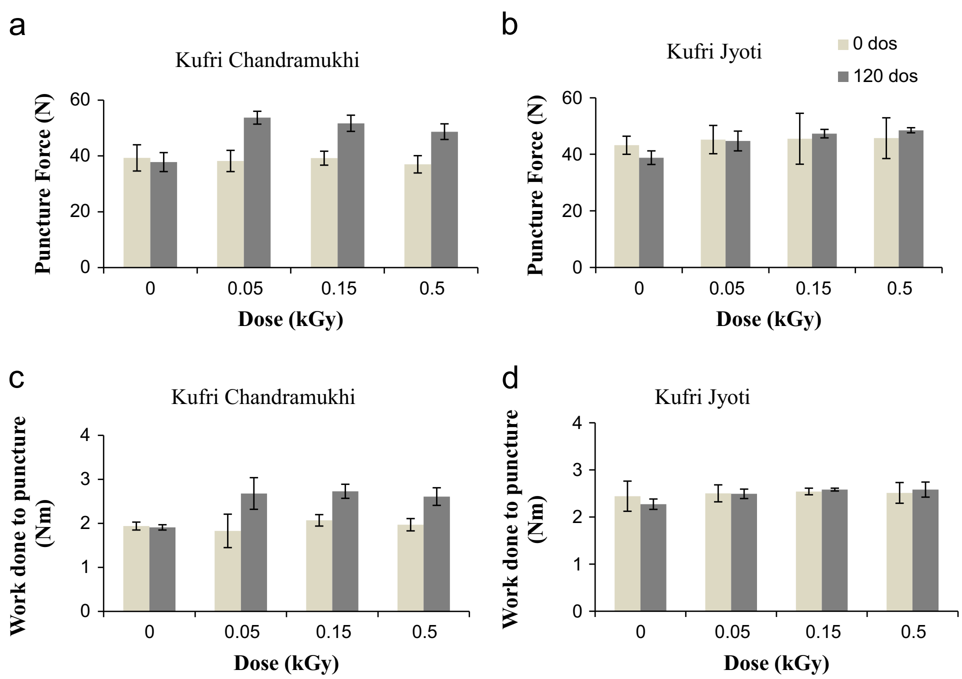

Fig. 1. Effect of γ-irradiation on the puncture force (N) and 'work done' to puncture (N m) unirradiated and irradiated 'Kufri Chandramukhi' and 'Kufri Jyoti' stored for 120 days at 12 °C.

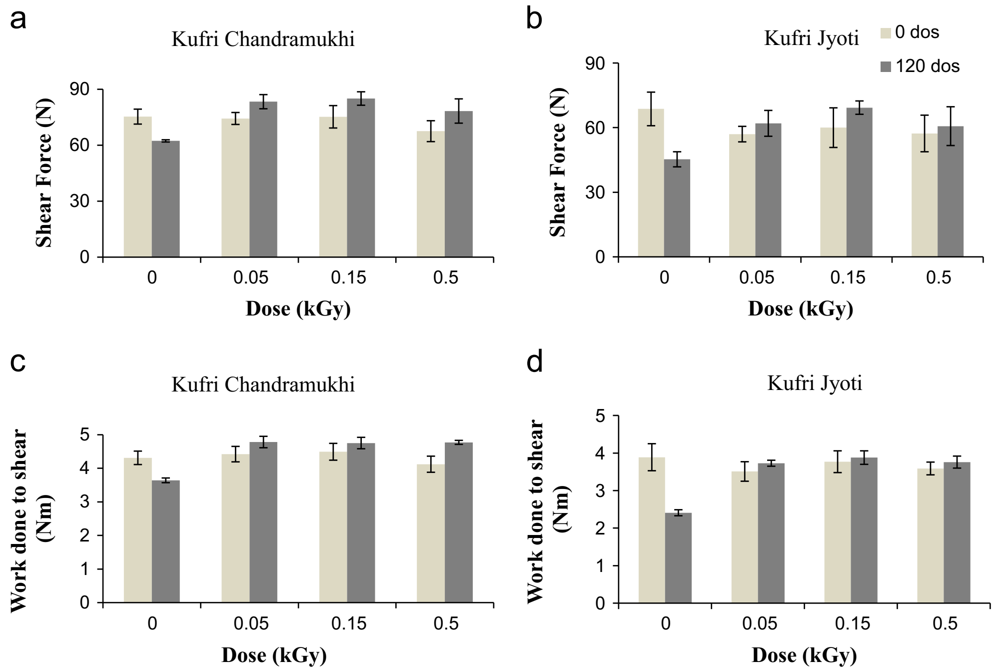

Fig. 2. Effect of γ-irradiation on the shear force (N) and 'work done' to shear (N m) unirradiated and irradiated 'Kufri Chandramukhi' and 'Kufri Jyoti' stored for 120 days at 12 °C.

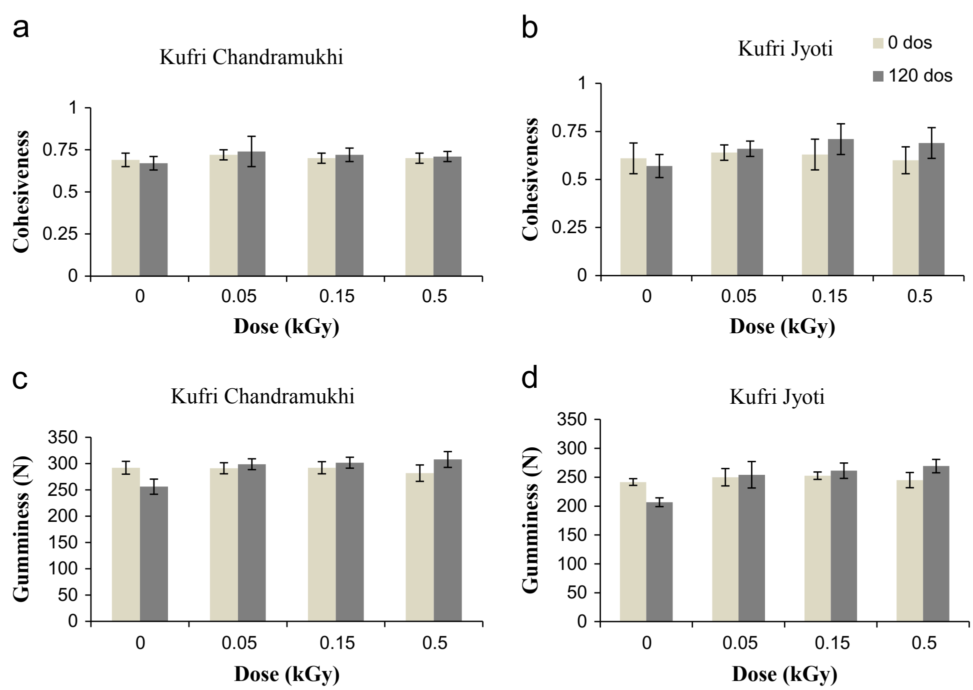

Fig. 3. Effect of γ-irradiation on cohesiveness and gumminess (N) of unirradiated and irradiated 'Kufri Chandramukhi' and 'Kufri Jyoti' stored for 120 days at 12 °C.

showed rigid cell wall. It also appears from the scanning electron micrographs that that there are more vacant cells in the control specimens suggesting greater mobilization of starch induced by sprouting. This difference between the unirradiated and irradiated specimens supports higher textural parameters of the irradiated samples compared to the controls.

3.3. Reducing and total sugars

No immediate effect of irradiation was observed but a dose dependent increased accumulation of both reducing and total sugars became conspicuous after storage. 'K. Chandramukhi' exposed to 0.15 and 0.5 kGy dose accumulated reducing sugars 28% and 31% higher respectively while 'K. Jyoti' accumulated reducing sugars 11% and 21% higher respectively (Fig. 5a and b). Similarly, the total sugar content was also observed to be significantly higher by 14–29% in 'K. Chandramukhi' and 6–14% in 'K. Jyoti' (Fig. 5c and d). The sugars in potato, although present in small amounts, play important role in the potato flavour for table purpose as well as the colour of the processed products (Woolfe, 1987; Mehta and Ezekiel, 2006). A number of authors reported increased sugar content in low dose irradiated samples

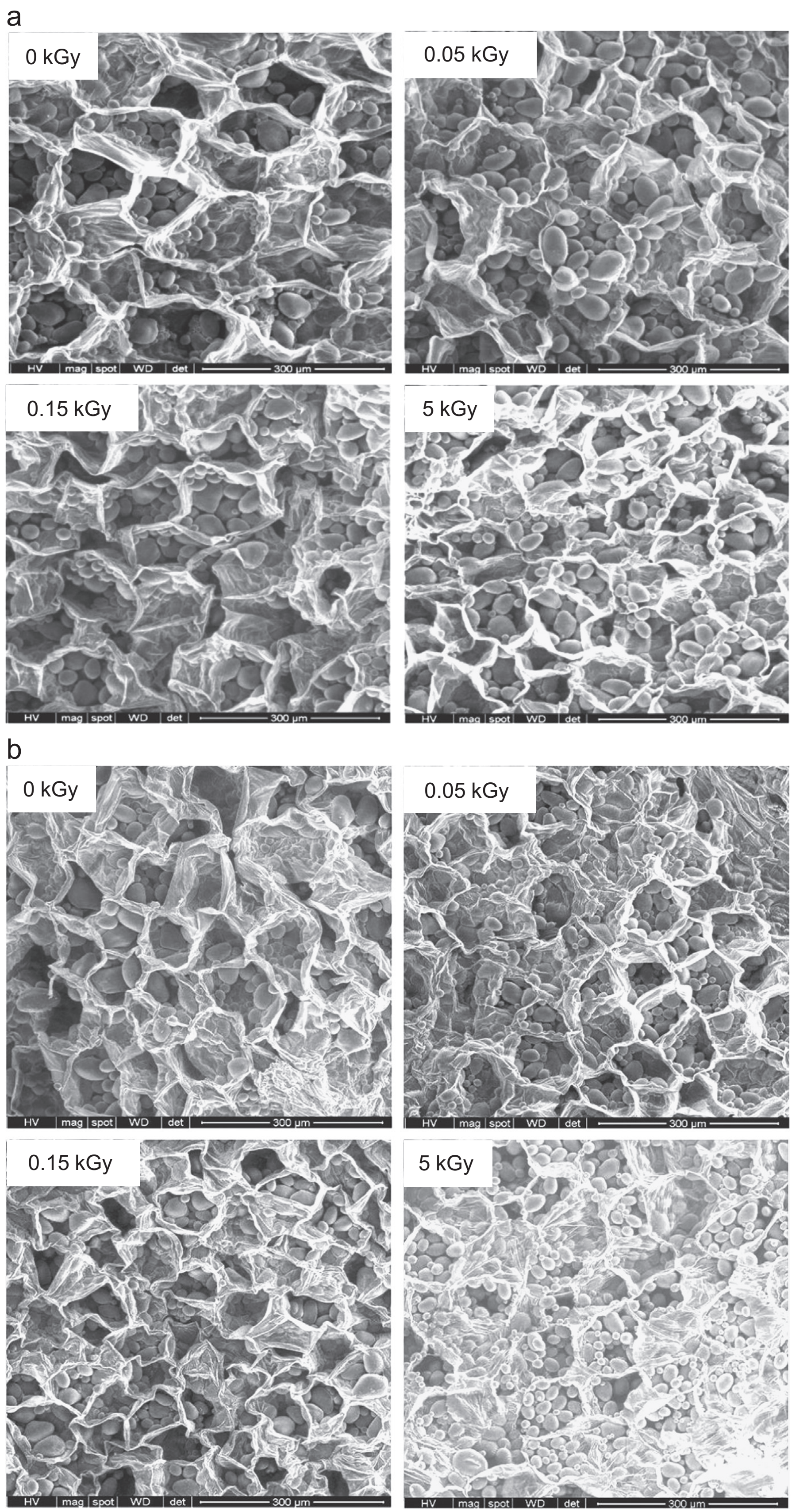

Fig. 4. Scanning electron micrographs of the flesh part of unirradiated and irradiated potatoes, (a) 'K. Chandramukhi', (b) 'K. Jyoti' (performed after 60 days of storage at 12 °C).

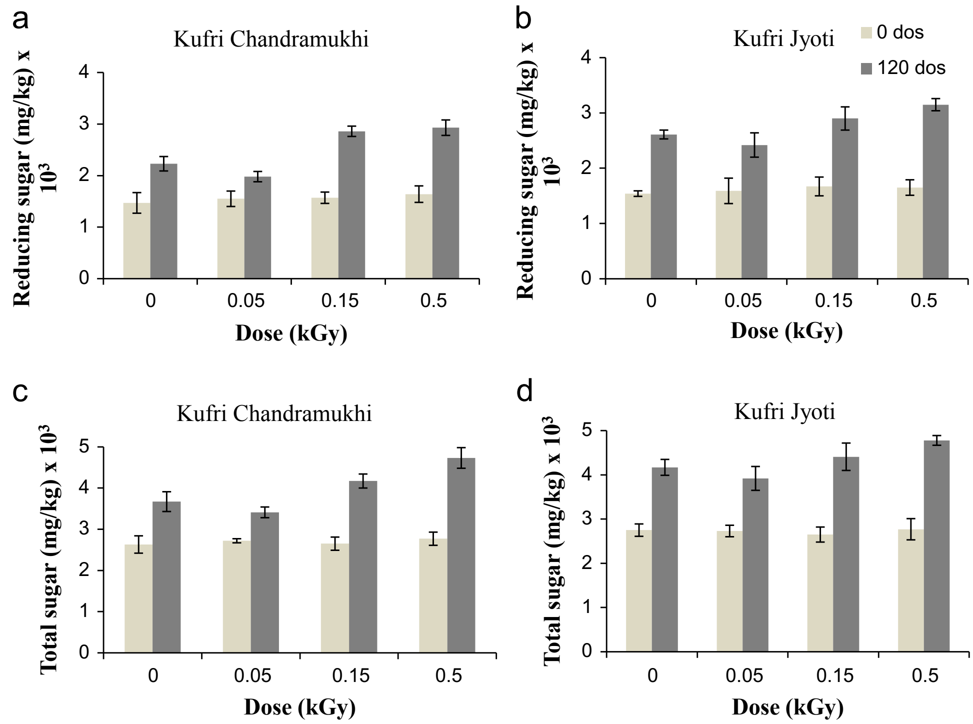

Fig. 5. Effect of gamma irradiation on the reducing sugar content (mg/kg fresh weight) and total sugar content (mg/kg fresh weight) of unirradiated and irradiated 'Kufri Chandramukhi' and 'Kufri Jyoti' stored for 120 days at 12 °C.

Table 1
Sprouting behavior, rotting and appearance of unirradiated and irradiated potatoes, cv. 'Kufri Chandramukhi' and cv. 'Kufri Jyoti' stored for 120 days at 12 °C.

Dose (kGy)	Sprout (%)	Max. spr. length (cm)	Rotting (%)	Appearance
Kufri Chandramukhi				
0.00	100	3.4 ± 0.8	6.00	S
0.05	00	0.0	0.00	F
0.15	00	0.0	0.00	F
0.50	00	0.0	14.20	F
Kufri Jyoti				
0.00	100	2.1 ± 0.5	6.25	S
0.05	00	0.0	0.00	F
0.15	00	0.0	0.00	F
0.50	00	0.0	19.04	F

S=shriveled, *F*=firm.

(Frazier et al., 2006; Ezekiel et al., 2008a, 2008b), but the minimum dose of 0.05 kGy at which least accumulation occurred is desirable as it would maintain the good taste as well as would be more suitable for the processing purpose.

3.4. Sprouting behavior, appearance and storage losses

The minimum dose applied (0.05 kGy) successfully inhibited sprouting of potatoes in both the cultivars (Table 1). All the irradiated tubers looked firm and showed no deterioration in their appearance during the storage period of 120 days while the unirradiated, sprouted tubers looked slightly shriveled. Irradiation is known to impair wound periderm formation (Thomas, 1982; Ghanekar et al., 1983), resulting in increased loss of the tubers due to rotting at 0.5 kGy. Even, the unirradiated controls of both the cultivars showed 6% rotting while no rotting loss was observed in the tubers irradiated with low doses up to 0.15 kGy. Higher rotting percentage of unirradiated controls compared to the low doses irradiated specimens might be related to low Polygalacturonase Inhibiting Protein (PGIP) activity in sprouted tubers compared to the non sprouted tubers. Low PGIP activity makes the tubers susceptible to microbial invasion (Glinka and Protsenko, 2001). Being meristematic and metabolically active, the bud tissue was particularly sensitive to irradiation and appeared black in the tubers irradiated with 0.5 kGy suggesting cell death.

4. Conclusion

The study showed that low dose gamma irradiation (0.05–0.15 kGy) with storage at 12 °C could be developed as an effective postharvest method for potato storage. The method successfully controlled the storage losses and preserved the textural quality of potato tubers, while accumulation of sugars was also low at the minimum dose of 0.05 kGy maintaining the good taste of the tubers.

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